

SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT WE, Hajime Noto, a citizen of Japan residing at Hachiooji-shi, Tokyo Japan, Yasuo Ishigure, a citizen of Japan residing at Tokorozawa-shi, Saitama Japan and Akihiko Hashimoto, a citizen of Japan residing at Koganei-shi, Tokyo Japan have invented certain new and useful improvements in

PSEUDO THREE DIMENSIONAL IMAGE GENERATING APPARATUS

Of which the following is a specification:-

TITLE OF THE INVENTION

PSEUDO THREE DIMENSIONAL IMAGE GENERATING  
APPARATUS

5    BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to an image generating apparatus, and more particularly, to an image generating apparatus for, a method of, and a 10 computer program for generating a pseudo three dimensional image from a plurality of images, and a computer readable recording medium storing the program.

2. Description of the Related Art

There are various conventional methods of 15 three dimensional measurement. The methods of three dimensional measurement are generally divided into two categories: passive methods and active methods. The stereo method is a typical passive method, and the light sectioning method is a typical active method.

20            In the stereo method, images of a subject are captured using two image capturing apparatuses disposed at a certain distance. The position of the subject is determined using optical triangulation based on the difference of the projected positions of the subject 25 in the images captured by the two image capturing apparatuses. In the light sectioning method, images of a subject are captured using a slit projection apparatus and an image capturing apparatus disposed at a certain distance. The position of the subject is determined using 30 optical triangulation based on the position in the captured image of a slit light projected on the subject.

Japanese Laid-open Patent Application No. 2000-329524 discloses a technique in which the depth of a

subject is determined using optical triangulation by illuminating the subject with light of which intensity changes position by position on the subject (light of which intensity increases from left to the right, for 5 example) and measuring reflective light of each position's light intensity. This technique, however, requires positioning the image capturing apparatus and the illuminating apparatus at a certain distance. It is difficult to embody this technique as a compact 3D image 10 generating apparatus.

Japanese Laid-open Patent Application No. 2000-121339 discloses another technique, in which there is a certain distance between a subject and an image capturing apparatus, using the so-called "time of flight" 15 principle by illuminating the subject with light of which intensity changes over time and measuring the intensity of reflective light. This technique, however, requires a special illuminating apparatus that illuminates the subject with intensity modulated light and an image 20 capturing apparatus equipped with a high-speed shutter for capturing the change in the intensity modulated light. It is difficult to embody this technique as a low cost 3D image generating apparatus.

Japanese Laid-open Patent Application No. 2- 25 079179 discloses a technique in which pseudo depth values are computed using tomograms captured with an X-ray CT, for example, each tomogram corresponding to a discrete depth value, in a manner where a transparent image is smoothly connected to an adjacent divisional image. This 30 technique, however, requires transparent images that are captured by an X-ray CT, for example, and are divided into tomograms each corresponding to a discrete depth value. It is difficult to embody this technique as a general purpose

3D image generating apparatus other than a medical apparatus.

Recently and continuing, mobile terminals equipped with a camera are being popularized. Although 5 images captured by such a camera are two dimensional, three dimensional images, if available, expand the application of images and increase the use of images. Since the conventional methods, both the passive methods and the active methods, use optical triangulation, an 10 image capturing apparatus and a slit projection apparatus, for example, need to be disposed at a certain distance. It is difficult to apply the conventional methods to mobile terminals. Additionally, the passive method generally requires a short measurement time, but results in low 15 accuracy and low quality 3D images. The active method generally results in high accuracy, but requires a long measurement time. The active method is better applied to an industrial apparatus. Since the other methods described above also require special apparatuses, they are useful 20 only for limited purposes.

#### SUMMARY OF THE INVENTION

Accordingly, it is a general object of the present invention to provide a novel and useful image 25 generating apparatus. Another and more specific object of the present invention is to provide a compact and easy-to-use pseudo three dimensional image generating apparatus and a method of generating a pseudo three dimensional image applicable to the compact and easy-to-use pseudo 30 three dimensional image generating apparatus.

The term "pseudo depth" indicates a depth (distance) that, in the case where the actual distance of a subject is unknown, is reasonably determined and

assigned to the subject as described below, instead of its actual depth. The term "pseudo 3D image" indicates a three dimensional image of which depth is the pseudo depth.

A pseudo 3D image generating apparatus, 5 according to the present invention, generates a pseudo three dimensional image of a subject from a plurality of images captured in various illumination conditions. The pseudo 3D image generating apparatus includes: an image storing unit that stores the images, and a depth computing 10 unit that computes pseudo depth value of a pixel in one of the images stored in said image storing unit based on an operation using the pixel value of said pixel and the pixel value of another pixel in another one of the images stored in said image storing unit, said other pixel 15 corresponding to said pixel.

A plurality of images of a subject captured under various illumination conditions are input to the pseudo 3D image generating apparatus. The images are compared thereby to compute the depth value of pixels. The 20 various illumination conditions may be the case in which the subject is illuminated by an illuminating apparatus and the case in which the subject is not illuminated by the illuminating apparatus. The greater the difference between images in the two cases is, the closer to the 25 image capturing apparatus the subject is. Although the depth value is discrete, one can generate a pseudo 3D image with discrete depths. The discrete depth value may be replaced with a continuous function so that the discrete depth values are smoothly connected. Accordingly, 30 the pseudo 3D image generating apparatus can avoid a "cardboard" effect and make observers perceive the generated pseudo 3D image as being natural and of high quality.

Other objects, features, and advantages of the present invention will become more apparent from the following detailed description when read in conjunction with the accompanying drawings.

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BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram showing a pseudo three dimensional image generating apparatus according to a first embodiment of the present invention;

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FIG. 2 is a flow chart showing processing for generating a pseudo three dimensional image according to the first embodiment;

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FIG. 3 is a flow chart showing a step of generating discrete depth data according to the first embodiment;

FIG. 4 is a flow chart showing the step shown in FIG. 3 in the case that average value is used;

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FIG. 5 is a flow chart showing a step of generating discrete depth data according to a second embodiment of the present invention;

FIG. 6 is a schematic diagram for explaining the effect of reflective index of a subject on the discrete depth data;

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FIG. 7 is a flow chart showing the step shown in FIG. 5 in the case that average value is used;

FIG. 8 is a flow chart showing a step of generating discrete depth data according to a third embodiment of the present invention;

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FIG. 9 is a flow chart showing the step shown in FIG. 8 in the case that average value is used;

FIG. 10 contains images and graphs for explaining processing for fitting a continuous function to a pseudo three dimensional image according to a fourth

embodiment of the present invention;

FIG. 11 is a set of images for explaining processing for smoothing a pseudo depth image according to a fifth embodiment of the present invention;

5 FIG. 12 is an example of the results of a smoothing filter according to the fifth embodiment;

FIG. 13 is a graph for explaining the determination of a threshold for generating the discrete depth data according to the embodiments of the present  
10 invention; and

FIG. 14 is a schematic diagram for explaining the adjustment of an object according to the embodiments of the present invention.

15 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiments of the present invention are described below in detail with reference to the drawings.

[FIRST EMBODIMENT]

20 FIG. 1 is a block diagram showing a pseudo three dimensional (3D) image generating apparatus according to a first embodiment. The pseudo 3D image generating apparatus 10 shown in FIG. 1 is connected to an image capturing apparatus 11 equipped with or connected to  
25 an illuminating apparatus 12 that illuminates a subject of which images are to be captured. The pseudo 3D image generating apparatus 10 is provided with an image storing unit 13, an operation unit 14, and a control unit 15. The image storing unit 13 stores the image data of the subject.  
30 The operation unit 14 computes pseudo depth of the subject by comparing a plurality of images captured in various illumination conditions with different intensities of illumination. The control unit 15 controls the above units.

FIG. 2 is a flow chart for explaining a method of generating a pseudo 3D image that is executed by the pseudo 3D image generating apparatus 10 showing in FIG. 1. The operation of the pseudo 3D image generating apparatus 10 is described with reference to the flow chart of the method of generating a pseudo 3D image shown in FIG. 2.

When generating a pseudo 3D image of a subject, illumination conditions and the number k of images to be captured are input (step S21). The illumination conditions and the number k of images may be fixed beforehand. The subject is illuminated in the j-th illumination condition with the illuminating apparatus 12, and an image captured by the image capturing apparatus 11 is input (step S22). The intensity of illumination differs in each illumination condition. The illuminating apparatus 12 illuminates the subject in response to an illumination signal (a pulse in synchronization with the shutter of the image capturing apparatus, for example). An image signal captured in the j-th order is stored in a frame memory j provided in the image storing unit 13 as image data (step S23). Processing of steps S22 and S23 is repeated until the number of captured image reaches the number k (step S24, S25).

After images are completely input, the stored image data are transferred from the frame memory 131-133 to the image operation unit 141 of the operation unit 14 in response to an instruction of the control unit 15 (step S26). The image operation unit 141 generates discrete depth data based on the images captured under different illumination conditions by performing operations (subtractions and/or divisions, for example) between the pixel values of corresponding pixels and comparing the

result of the operations with a predetermined threshold value (step S27). A detailed description is given of the discrete depth data below.

The image operation unit 141 performs pre-processing for generating color information among the images and for computing depth values. The color information is generated, for example, by converting the images so that the contrast of each image becomes the maximum and extracting the image of the highest contrast.

5 The converted images may be appropriately weighted and combined. The pre-processing may include edge detection, object detection by color, and expansion and shrinkage after binarization, for example. A combination of the above processing methods may be selected by the control

10 unit 15.

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The depth computing unit 142 computes a pseudo depth value of each pixel using the discrete depth data generated by the image operation unit 141 (step S28).

Illuminating the subject is required for computing the depth value of the subject. The image capturing apparatus 11 and the illuminating apparatus 12 may be disposed side by side. Accordingly, the pseudo 3D image generating apparatus 10 may become more compact than conventional apparatuses. The pseudo 3D image generating apparatus 10 may be built into a mobile terminal, a notebook computer, and a digital camera, for example.

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FIG. 3 is a flow chart showing the step of generating the discrete depth data (step S27) shown in FIG. 2. In this embodiment, the depth value is assumed to be binary in order to make the description easy. Two illumination conditions, that is, "with illumination" and "without illumination" are set, and two images are captured. The pixel value of i-th pixel of the image data

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captured "with illumination" is denoted as  $A_i$ , and the  
pixel value of  $i$ -th pixel of the image data captured  
"without illumination" is denoted as  $B_i$ . Binary data  
qualitatively indicating the discrete depth is denoted as  
5  $C_i$ . When computing a depth value, a threshold  $n$   
and the image size  $s$  are determined (step S31). The  
threshold  $n$  is a parameter that divides pixels of the  
image into two categories, that is, pixels close to and  
10 pixels distant from the image capturing apparatus 11. The  
threshold  $n$  is arbitrary determinable. The determination  
of the threshold  $n$  is described below. The image size  $s$  is  
multiplied by the number of pixels in the width directions (x)  
15 directions (y) of the input image data. The pixel value  $B_i$   
is subtracted from the pixel value  $A_i$ . If the result of  
the subtraction is equal to or greater than the threshold  
 $n$ , then  $C_i$  is set equal to 1. If not,  $C_i$  is set equal to 0  
(steps S32 - S34). Processing of steps S32 - S34 is  
20 repeated for all the pixels of the image data (steps S35 -  
S36). Pixels of which the value of the binary  
discrete depth data  $C_i$  is 1 are determined to be close to  
the image capturing apparatus 11. The other pixels are  
25 determined to be distant from the image capturing  
apparatus 11. As described above, the binary data  $C_i$   
indicates the discrete depth of pixels qualitatively based  
on the comparison with the threshold  $n$ . A pseudo 3D image  
can be generated at high speed without excessive  
30 computational load by using the result of binary  
processing as the pseudo depth value.  
Multi-level depth values may be computable  
by using binary processing based on a plurality of images

captured under different illumination conditions or binary processing using different thresholds. In this case, one of the images is used as a reference image, and operations between each of the other images and the reference image 5 may be performed.

FIG. 4 is a flow chart showing a variation of the step of generating the discrete depth data (step S27 in FIG. 2) described with reference to FIG. 3. The step of generating discrete depth data shown in FIG. 4 is 10 different from the step of generating the discrete depth data shown in FIG. 3 in that, when the binary data  $C_i$  of a pixel  $i$  is computed, average values  $A'i$  and  $B'i$  of several pixels around the pixel  $i$  are used instead of the pixel values  $A_i$  and  $B_i$ , respectively. Since the average values 15 are used, even if data of the plurality of images that are to be compared are deviated, the effect of the deviation can be reduced. If the range of pixels to be averaged is determined appropriately, the pseudo 3D image generating apparatus 10 is applicable to moving images too. Since the 20 S/N ratio is improved by averaging, the results of operations and comparisons become stable.

[SECOND EMBODIMENT]

A second embodiment of the present invention is described below. The pseudo 3D image generating 25 apparatus and the method of generating a pseudo 3D image of the second embodiment are identical to those of the first embodiment except for the step of generating discrete depth data. Accordingly, only the difference is described below.

30 FIG. 5 is a flow chart showing a process of generating discrete depth data according to the second embodiment. The depth value is assumed to be binary data indicating "close" and "distant" in the second embodiment.

The pixel value of the i-th pixel of image data "with illumination" is denoted as  $A_i$ , the pixel value of the i-th pixel of image data "without illumination" is denoted as  $B_i$ , and binary data qualitatively indicating discrete 5 depth is denoted as  $C_i$ .

When computing depth value, a threshold  $m$  and image size  $s$  are determined first (step S51). The threshold  $m$  is a parameter for assigning binary discrete depth data to an image. The threshold is arbitrarily 10 determinable. The image size  $s$  is the number of pixels in the width direction (x) multiplied by the number of pixels in the height direction (y) of input image data. If the ratio of the pixel value  $A_i$  to the pixel value  $B_i$  is equal 15 to or more than the threshold  $m$ , then  $C_i$  is set at 1, otherwise,  $C_i$  is set at 0 (steps S52 – S54). Processing of steps S52 – S54 is repeated for all the pixels of the image data (steps S55 – S56).

Pixels of which binary data  $C_i$  is 1 are determined to be close to the image capturing apparatus 11, 20 and the other pixels are determined to be distant from the image capturing apparatus 11.

As shown in FIG. 5, division of the pixel values  $A_i$  and  $B_i$  is used in the process of generating the discrete depth data according to the second embodiment. In 25 a case that there are a plurality of subjects of which reflective indexes are different, if the discrete depth data  $C_i$  is determined based on the division of the pixel values  $A_i$  and  $B_i$  as it is determined in the second embodiment, the difference of reflective indexes does not 30 affect the discrete depth data  $C_i$ . In such a case, if the discrete depth data  $C_i$  is determined based on the subtraction of the pixel values  $A_i$  and  $B_i$  as it is determined in the first embodiment, the difference in

reflective index may affect the discrete depth data  $C_i$ . Because the reflective index differs subject by subject, a subject of high reflective index may be determined to be closer to the image capturing apparatus 11 than it 5 actually is, and a subject of low reflective index may be determined to be more distant from the image capturing apparatus 11 than it actually is. However, this problem is negligible in many cases such as a far-and-near separation in which the distance to the subjects needs to be very 10 coarsely measured.

FIG. 6 is a schematic diagram for explaining the effect on the discrete depth data  $C_i$ , of the difference in the reflective index of a plurality of subjects of different reflective indexes. As shown in FIG. 15 6, subjects 621 and 622 are equally distant from an image capturing apparatus 61 and an illuminating apparatus 63. The reflective indexes of the subjects 621 and 622 are  $r_a$  and  $r_b$ , respectively, which are different from each other. When the image capturing apparatus 61 captures images of 20 the subjects 621 and 622, the captured images are displayed on a display apparatus 64. Assuming that the light intensity that reaches the subjects 621 and 622 from the illumination apparatus 63 is  $X$ , the subjects 621 and 622 are displayed on the display apparatus 64 as objects 641 and 642 of 25 which luminance is  $r_a*X$  and  $r_b*X$ , respectively. Likewise, if the light intensity that reaches the subjects 621 and 622 from the illumination apparatus 63 is  $Y$ , the subjects 621 and 622 are displayed on the display apparatus 64 as objects 641 and 642 of 30 which luminance is  $r_a*Y$  and  $r_b*Y$ , respectively. The difference in luminance of the subject 621 is  $r_a*(X-Y)$ , and the difference in luminance of the subject 622 is  $r_b*(X-Y)$ . Although the subjects 621 and 622 are equally

distant from the image capturing apparatus 61, their luminances are different.

If the discrete depth data  $C_i$  is computed by division as it is computed in the second embodiment, the 5 ratio of luminance of the subject 621 is  $X/Y$ , and the ratio of luminance of the subject 622 is also  $X/Y$ . Since the difference in reflective index is canceled, the ratio of luminance of a subject is equal to that of an equally distant subject.

10 In the case that a subject close to the image capturing apparatus includes a portion made of material of low reflectivity, the difference in luminance of the portion may be less than a predetermined threshold, and is determined to be distant from the image capturing 15 apparatus, which is wrong. However, the ratio of luminance of the portion is greater than a predetermined threshold, and is determined to be close to the image capturing apparatus, which is correct.

20 Multi-level depth values may be computable by combining binary processing based on a plurality of images captured under different illumination conditions or binary processing using different thresholds in the same manner as the first embodiment.

25 FIG. 7 is a flow chart showing a variation of the step of generating the discrete depth data (step S27 in FIG. 2) described with reference to FIG. 5. The step of generating discrete depth data shown in FIG. 7 is different from the step of generating the discrete depth data shown in FIG. 5 in that, when the binary data  $C_i$  of a 30 pixel  $i$  is computed, average values  $A'i$  and  $B'i$  of several pixels around the pixel  $i$  are used instead of the pixel values  $A_i$  and  $B_i$ , respectively. Since the average values are used, even if data of the plurality of images that are

to be compared are deviated, the effect of the deviation can be reduced. If the range of pixels to be averaged is determined appropriately, the pseudo 3D image generating apparatus 10 according to this variation to the second 5 embodiment is applicable to moving images too. Since S/N ratio is improved by averaging, the results of operations and comparisons become stable.

A method of determining the thresholds used in the first and second embodiments is described with 10 reference to FIG. 13. FIG. 13 is a graph showing the relationship between the distance and illumination of a subject. Curves 1310 and 1320 show the change of illumination of the subject over distance under illumination states of differing light intensity. The 15 graph indicates that the light intensity that reaches the subject from the illuminating apparatus is inversely proportional to the square of distance.

In the case of the light intensity 1310, the light intensity that reaches a subject distant by  $2L$  20 becomes  $Y/4$ , where  $Y$  is the light intensity that reaches a subject distant by  $L$ . A threshold  $n$  is shown in the graph. Pixels of which illumination is equal to or greater than the threshold  $n$  are closer to the image capturing apparatus than a distance denoted by a reference numeral 25 1311. Likewise, in the case of the light intensity 1320, pixels of which illumination is equal to or greater than the threshold  $n$  are closer to the image capturing apparatus than a distance denoted by a reference numeral 1321. Accordingly, if the discrete depth data are 30 determined based on the subtraction of pixel values as they are determined in the first embodiment, a threshold corresponding to a distance can be determined depending on the illumination light intensity. In this case, however,

it is necessary to appropriately assume the reflective index of subjects. The effect of outdoor daylight (corresponding to the illumination condition without the illumination by the illuminating apparatus) does not need 5 to be taken into account since it is canceled when the subtraction is performed. A more appropriate threshold is determinable by adjusting the assumed reflective index based on the generated discrete depth data.

On the other hand, if the discrete depth 10 data are determined based on the division of pixel values as they are determined in the second embodiment, the threshold corresponding to a distance can be determined based on the light intensity projected by the illuminating apparatus and the outdoor daylight (or the indoor lighting, 15 for example).

The outdoor daylight, for example, if it is constant, increases the minimum value of the illumination shown in FIG. 13 by providing a constant offset. The relative distance of the subject is determinable by the 20 division. For example, since the illumination light intensity decreases inversely proportional to the square of distance, if the result of division of a pixel is four times as great as the result of division of another pixel, the pixel is half as distant from the image capturing 25 apparatus as the other pixel is.

Assuming that the outdoor sunlight projected to the subject is constant, one can determine the threshold corresponding to a distance. In this case, the effect of difference in reflective index of the subject 30 does not need to be taken into account since it is canceled by the division.

A more appropriate threshold is determinable by adjusting the assumed illumination light intensity

based on the generated discrete depth data.

[THIRD EMBODIMENT]

A third embodiment of the present invention is described below. The pseudo 3D image generating apparatus and the method of generating a pseudo 3D image according to the third embodiment are identical to those of the first embodiment except for the process of generating discrete depth data. Accordingly, only the difference is described below.

FIG. 8 is a flow chart showing a process of generating discrete depth data according to the third embodiment. The depth value is assumed to be binary data indicating "close" and "distant" as in the second embodiment. The pixel value of the  $i$ -th pixel of image data "with illumination" is denoted as  $A_i$ , the pixel value of the  $i$ -th pixel of image data "without illumination" is denoted as  $B_i$ , and binary data qualitatively indicating discrete depth is denoted as  $C_i$ .

When computing depth value, a threshold  $n$  for subtraction, a threshold  $m$  for division, a predetermined pixel value  $p$ , and image size  $s$  are determined first (step S81). The threshold  $n$  for subtraction, the threshold  $m$  for division, and the predetermined pixel value  $p$  are parameters for assigning binary discrete depth data to an image. These parameters are arbitrarily determinable. The image size  $s$  is the number of pixels in the width direction ( $x$ ) multiplied by the number of pixels in the height direction ( $y$ ) of input image data. If the pixel value  $A_i$  is equal to or greater than the predetermined pixel value  $p$ , the discrete depth data are generated through the process of generating discrete depth data using the threshold  $n$ , the process described in connection with the first embodiment.

Otherwise, the discrete depth data are generated through the process of generating discrete depth data using the threshold  $m$ , the process described in connection with the second embodiment. Collectively the two processes are 5 shown in steps S82 - S86 in FIG. 8.

Pixels of which binary data  $C_i$  is 1 are determined to be close to the image capturing apparatus 11, and the other pixels are determined to be distant from the image capturing apparatus 11.

10 As described above, the discrete depth data computed by subtraction are assigned as the pseudo distance to pixels of which luminance is equal to or higher than the predetermined pixel value  $p$ . In this case, since the computational load is low, the pseudo 3D image 15 generating apparatus according to the third embodiment can generate the pseudo 3D image at high speed. The discrete depth data computed by division, however, are assigned as the pseudo distance to pixels of which luminance is lower than the predetermined pixel value  $p$ . In this case, if the 20 luminance of a portion of the image data is lower than the predetermined pixel value due to a low reflective index, the discrete depth data computed by division indicates the actual distance more accurately.

25 Multi-level depth values may be computable by combining binary processing based on a plurality of images captured under different illumination conditions or binary processing using different thresholds in the same manner as the first embodiment.

30 FIG. 9 is a flow chart showing a variation of the step of generating the discrete depth data (step S27 in FIG. 2) described with reference to FIG. 8. The step of generating discrete depth data shown in FIG. 9 is different from the step of generating the discrete depth

data shown in FIG. 8 in that, when the binary data  $C_i$  of a pixel  $i$  is computed, average values  $A'_i$  and  $B'_i$  of several pixels around the pixel  $i$  are used instead of the pixel values  $A_i$  and  $B_i$ , respectively. Since the average values 5 are used, even if data of the plurality of images that are to be compared are deviated, the effect of the deviation can be reduced. If the range of pixels to be averaged is determined appropriately, the pseudo 3D image generating apparatus 10 according to the second embodiment is 10 applicable to moving images too. Since S/N ratio is improved by averaging, the results of operations and comparisons become stable.

According to a variation of the third embodiment, a plurality of predetermined pixel values  $p_1$ , 15  $p_2$ , ..., may be used. In the case that two predetermined pixel values  $p_1$  and  $p_2$  are used, for example, where  $p_1 > p_2$ , if a pixel value is greater than  $p_1$ , a threshold  $n_1$  is used for the subtraction operation. If the pixel value is greater than  $p_2$ , another threshold  $n_2$  is used for the 20 subtraction operation. If the pixel value is equal to or smaller than  $p_2$ , yet another threshold  $n_3$  is used for the subtraction operation. The different thresholds may be used depending on the pixel value. The thresholds may be determined region by region as they are determined in the 25 case of adaptive binarization.

[FOURTH EMBODIMENT]

As described above, discrete depth data are generated (step S27 of FIG. 2) and the discrete depth data are used as the depth of a pseudo 3D image, as is, in the 30 first through third embodiments. Specifically, a predetermined distance (depth) of close subjects and a predetermined distance (depth) of distant subjects are assigned to the value of  $C_i$ , that is, 1 and 0. According

to the fourth embodiment of the present invention, the generated discrete distance data are further processed so that a pseudo 3D image makes observers perceive more reality (step S28 of FIG. 2).

5 of generating a pseudo 3D image according to the fourth embodiment of the present invention. The algorithm of the method is described below with reference to FIG. 10.

10 the discrete depth data generated according to any one of the first through third embodiments. Since the discrete depth data  $C_i$  is binary data, a discrete depth data image 102 is a two dimensional black-and-white image indicating 15 discrete depth data image 101 can be divided based on  $C_i$ . The original image 101 can be divided based on the discrete depth data image 103 and a background image 104. The method such as the methods according to the first through third embodiments.

20 Objects are extracted from the foreground image 103 by classifying regions. The black portion in the foreground image 103 is a region existing on another divisional image 1031, 1032 in which adjacent pixels 25 remaining in the foreground image 103 are grouped are so called objects corresponding to the subjects. In this case, the objects are extracted by grouping together adjacent remaining pixels. The objects may be extracted by dividing the original image 101 based on color information. The 30 depth values of the objects 1031 and 1032 in the foreground image 103 are re-computed so that the depth values of the objects 1031 and 1032 are smoothly connected to the depth values of the background image 104.

Specifically, the edges of the objects 1031 and 1032 that steeply rise from or fall to the background image 104 are replaced with appropriately determined smooth functions.

Three examples are illustrated in FIG. 10.

5 An image 105 shows the case in which the depth value of the objects is replaced with a quadratic function that changes in the width directions of the objects. An image 106 shows the case in which the depth value of the objects is replaced with a function of which center portion is

10 constant and each shoulder portion is a quadratic function that changes in the width directions. An image 107 shows the case in which the depth value of the center portion of each object is constant and the depth value of the peripheral portion of each object is replaced with a

15 quadratic function that changes along lines extending spokewise from the center of gravity of each object.

When generating the image 105 in which the depth value of the objects is replaced with a quadratic function that changes in the width directions of the objects, the objects are scanned horizontally, and pseudo depth values computed based on the quadratic function are provided to each pixel on the scan line. For example, when a line 1051 is scanned, the left and right edges of the object on the line 1051 are detected. The depth value of the background image 104 is set as the minimum, and the greatest depth value of the foreground image 103 that is most distant from the background image 104 is set as the maximum. The depth values of the objects are replaced with values of a quadratic function that crosses the minimum at the left and right edges of the object and the maximum at the center of the object. It is possible to compute pseudo depth of a captured 2D image and generate a pseudo 3D image without measuring actual depths of subjects.

When generating the image 106 in which the depth value of the objects is replaced with a function of which center portion is constant and each shoulder portion is a quadratic function, the objects are scanned

5 horizontally, and pseudo depth values are assigned to each pixel. For example, when a line 1061 is scanned, the left and right edges of the object on the line 1061 are detected. The depth value of the background image 104 is set as the minimum, and the greatest depth value of the

10 foreground image 103 that is most distant from the background image 104 is set as the maximum. The depth value of the object 1031 is replaced with a function 1062. The function 1062 is a composite function including a quadratic function that crosses the minimum at the left

15 (right) edge of the object 1031 and the maximum at a position 15% left (right) from the center of the object 1031, and a linear function that is constant at the maximum in the center range of 30%. Since the center portion of the object is emphasized, observers watching

20 the image 106 perceive that the object 1031 is closer to themselves than when they are watching the image 105.

When generating the image 107 in which the depth value of the center portion of each object 1031 and 1032 is constant and the depth value of the peripheral portion of each object is replaced with a quadratic function that changes along lines extending spokewise from the center of gravity of each object, the center of gravity of the object 1031 is computed, and pseudo depth values are provided for each line that crosses the

25 computed center of gravity and an edge of the object 1031. For example, when the depth values on a line 1071 are computed, the crossing point of the edge of the object 1031 and the line 1071 are detected. The depth value of

the background image 104 is set as the minimum, and the greatest depth value of the foreground image 103 that is most distant from the background image 104 is set as the maximum. The depth values are replaced with the values of 5 a function 1072. The function 1072 is a function that crosses the minimum at the crossing points and is constant at the maximum in the 30% range between the crossing points centered on the center of gravity.

Since the center portion of the object is 10 emphasized, observers watching the image 107 perceive that the object 1031 is closer to themselves than when they are watching the image 105. Because the depth values are computed along lines extending spokewise from the center of gravity of the object, the edge of the object is 15 uniformly smoothed despite the slope of the boundary of the object. Observers watching the image 107 perceive that the pseudo 3D image is more natural than they do when watching the image 106.

[FIFTH EMBODIMENT]

20 FIG. 11A and 11B show images for explaining a method of generating a pseudo 3D image according to a fifth embodiment of the present invention. FIG. 11A shows the original depth values 1110 of pixels of a divisional image computed by the method of generating a pseudo 3D 25 image according to the fourth embodiment. FIG. 11B shows depth values 1130 after smoothing in which a 7X7 pixel range centered on each pixel is averaged.

FIG. 12 illustrates the smoothing filter used for smoothing according to the fifth embodiment. In 30 this case, the smoothing filter applied to the depth values 1110 is a simple moving average filter in which the pixel values of all pixels in the filter size (7X7), at which center is the pixel to be processed, are multiplied

by a multiplicative inverse (1/49) of the filter size and then are summed. The filter size is arbitrarily changeable. It is possible to use another filter for smoothing such as a weighted moving average filter of which each matrix in 5 the filter is appropriately weighted and a Gaussian filter of which each matrix in the filter is weighted in accordance with a Gaussian distribution.

An enlarged image 1112 of FIG. 11A shows a portion around the jaw of the original depth values 1110. 10 Another enlarged image 1132 of FIG. 11B shows the portion 1131 around the jaw of the smoothed depth values 1130. It is apparent from the comparison between the enlarged images 1112 and 1132 that smoothing processing reduces steep change in the depth values.

15 If there is a steep change in the depth values of an object that is generated by the method of generating a pseudo 3D image according to the first through fourth embodiments, observers watching the pseudo 3D image may feel uneasy about it. If there is a steep 20 change in the depth values in a boundary portion of an object, since the object looks apart from other adjacent divisional images, observers watching the pseudo 3D image may feel uneasy about it too.

In the case where there is a steep change in 25 the depth values in an object, smoothing the computed depth values prevents the observers from feeling uneasy about the pseudo 3D image. Further, in the case where there is a steep change in the depth values in a boundary portion of an object, smoothing makes the connection 30 between the depth values of the object and the depth values of adjacent divisional images smooth, and prevents the observers from feeling uneasy about the pseudo 3D image.

It is obvious that a duly designed computer program can cause a computer to perform the steps shown in the above flow charts. It is also obvious that such a computer program can be stored in a computer readable recording medium.

According to the first through fifth embodiments, a subject of which image is captured is extracted from the captured image as an object based on the discrete depth data. Pseudo depth values are assigned to the pixels included in the extracted object. According to another embodiment of the present invention, the object may be extracted by conventional methods such as edge detection and/or color information. Pseudo depth values may be assigned to the pixels included in the object extracted with the conventional methods based on the discrete depth data according to the present invention. The edge detection may be performed by a first derivation filter and a second derivation filter, for example. An object may be extracted using the color space and color intensity.

An object extracted based on discrete depth data may be adjusted using an object extracted by edge detection and/or color information. FIG. 14 is a schematic diagram for explaining the adjustment of an object. A reference numeral 1410 denotes the contour of an object extracted by edge detection, for example. A reference numeral 1420 denotes a region extracted based on discrete depth data. A discrete depth data image may be deviated from a true image that reflects actual depth of the object due to the difference in reflective index of the object and/or movement of the object. The deviation is adjusted using the contour 1410. Specifically, the contour of the region 1420 extracted based on the discrete depth data is

adjusted to the nearest portion of the contour 1410. For example, a point 1431 is adjusted to a point 1441, and a point 1432 is adjusted to a point 1442.

Not only the contour but also the discrete depth data image is adjustable by removing a small region and/or filling up a small hole in the discrete depth data image. For example, if a portion of a subject (eyes of a person and buttons, for example) is not captured as the object, the portion may be filled up. If a portion that is not included in the subject is captured as the object, the portion may be removed. The size of the portion to be filled up or removed may be determined based on a rule of thumb. Likewise, if the gap between two objects is small, the gap may be filled up thereby to combine the two objects. The gap size may be determined based on a rule of thumb in the same manner as the size of a portion to be filled up or removed.

The resolution of images may be reduced in order to reduce computational load before generating the discrete depth data. The amount of computation can be reduced by reducing the resolution of the images. If an extracted object is deviated due to the effect of reflective index and the movement of a subject, the resolution of the depth values become coarse compared to texture. Accordingly, the contour of the discrete depth data image deviating from a true image is made obscure, and the deviation looks smaller.

If the resolution of the averaged image is reduced, the S/N ratio of the averaged image can be improved as the image is smoothed by a smoothing filter.

The signal S indicates infinite grey scale image information captured without any noise. The noise N indicates the amount of noise including all noise factors

such as optical and electrical noise and quantization noise caused by quantization error.

Only pixels that remain after the reduction of resolution need to be averaged. For example, if every 5 other pixel is averaged in the width directions and the height directions, the number of pixels to be averaged may be reduced down to 1/4 of number before the resolution reduction. Generating the discrete depth data using divisional operation according to the second embodiment is 10 highly sensitive to noise in the image. Even in this case, the S/N ratio can be improved by reducing the resolution of the image.

Not all of the above processing necessarily needs to be performed, but only desired processing may be 15 performed on a necessity basis in response to the instruction of the control unit 15.

As described above, the present invention provides the following effects.

Since the image capturing apparatus and the 20 illuminating apparatus may be disposed adjacent to each other, a pseudo 3D image generating apparatus according to an aspect of the present invention can be made more compact than a conventional apparatus.

If the result of a simple binarization 25 process is used as the pseudo distance, because computational load is small, a pseudo 3D image generating apparatus according to another aspect of the present invention can generate a pseudo 3D image at high speed.

A pseudo 3D image generating apparatus 30 according to yet another aspect of the present invention can easily generate continuous pseudo depth values without any complex measurement.

A pseudo 3D image generating apparatus

according to yet another aspect of the present invention can reduce uneasy feelings of observers caused by a steep change in the computed pseudo depth values.

The present invention is not limited to 5 these embodiments, but various variations and modifications may be made without departing from the scope of the present invention.

This patent application is based on Japanese priority patent application No. 2002-275471 filed on 10 September 20, 2002, the entire contents of which are hereby incorporated by reference.